REMOTE SENSING APPLICATIONS FOR GROUNDWATER TARGETING

IQBALUDDIN
Remote Sensing Application Centre, Aligarh Muslim University, Aligarh

Abstract *The growing demand on the fresh water resources has made it imperative to optimally use the groundwater, which in the Indian context is approximately 40% of the total fresh water resources of the country. This requires assessment of groundwater resources and watershed characteristics. The occurrence of groundwater depends upon the water holding capacity of rocks and its availability on the water yielding capacity of stratum (i.e. storage coefficient and specific yield). Groundwater targeting using remote sensing implies search of occurrence of groundwater and not its availability. Since groundwater occurs below the zone of aeration, the sensors cannot directly record groundwater occurrences, its targeting is indirect wherein we look for factors which control occurrence of groundwater.*

WATER IN EARTH SYSTEM

Water is essential for sustenance of life. Table 1 presents the distribution of water in the earth system. The subsurface water accounts for 0.615% of the total fresh water (Fetter, 1980). Subsurface water which gets its annual replenishment from precipitation, is the most widely distributed resource of the earth and is the chief source of drinking water supply and dependable irrigation in many water scarce areas of the world. The subsurface water occurs as vadose water in the zone of aeration and as groundwater in the zone of saturation. Excluding the polar icecaps and glaciers, groundwater is the largest resource of freshwater on earth. However, the growing demand on fresh water resources has made it imperative to optimally use the groundwater, which in the Indian context is approximately 40% (45.23 m.ha.m) of the total fresh water resources of the country (113 m.ha.m). Optimal utilization requires proper assessment of groundwater resources and watershed characteristics.

Table 1 The distribution of water in earth system

Occurrence of Water	Percent
Water in the oceans and seas	97.20
Water as in ice caps and glaciers	2.14
Groundwater down to depth of 800 metres	0.001
Water in the rivers, reservoirs and lakes	0.005
Water in the atmosphere	0.001
Total	99.957

The occurrence of groundwater depends upon the water holding capacity of rocks and its availability on the water yielding capacity of stratum (i.e. storage coefficient and specific yield). Groundwater targeting will restrict the scope of Remote Sensing Applications to search of occurrence of groundwater and not its availability. Since it occur below the zone of aeration the sensors cannot directly record groundwater occurrences, its targeting is indirect, we look for factors which control occurrence of groundwater, the water holding capacity of rocks is targeted by Remote Sensing Applications.

ATMOSPHERIC WINDOWS FOR GROUNDWATER TARGETING

The atmospheric windows, available sensors and systems which can be useful for groundwater targeting are given in Tables 2 and 3.

Table 2 Available sensors for groundwater targeting

Vehicle /Sensor	Spectral bands	Nominal Spatial Resolution	Appropriate image/ scene area coverage	Freq. of coverage	Periods of data availability	Data center
Operational						
NOAA/AVHRR	0.6-0.75μm 10.5-12.50μm	1km	Sub-Continent	1/day – visible 2/day – Infrared	1972 to 1978	Suitland, MD
ESSA-NOAA /AVCS-SR	Visible (AVCS) 0.5-0.75μm 10.5-12.50μm	4km	Sub-Continent	1/day – Visible 2/day –SR	1966 to present	Suitland, MD
SMS-GEOS/ VISSR	0.6-0.7μm 10.5-12.50μm	1km	1/3 of Globe Western hemisphere	Several times Per day	1974 to present	Suitland, MD
TIORS-N/ NOAA AVHRR	4-5 bands Visible near Infrared thermal, infrared	1.1km	Sub-Continent	1/day Visible/ Near Infrared 2/day Thermal Infrared	1978 to present	Suitland, MD
Quasi-operational						
LANDSAT MSSTM	0.5-0.6μm 0.6-0.7μm 0.7-0.8μm 0.8-1.1μm 10.5-12.5μm	80 m 240 m	34,000 km	Once every 18 days (9 days with two satellites)	1972 to present	Sioux Falls, SD
High Altitude NASA Aircraft		10m approx	400-900 km^2	Variable	Occasional coverage in selected areas for 10 years or more	Sioux Falls, SD

Contd...

Table 2 (contd.)

Vehicle /Sensor	Spectral bands	Nominal Spatial Resolution	Approriate image/ scene area coverage	Freq. of coverage	Periods of data availability	Data center
Research and Development						
Skylad-EREP/Multispectral Cameras Spectrometers	Visible Near Infrared Thermal, Infrared	10 - 70 m	10,000 - 30,000 km^2	Variable	1973-1974 (three flights)	Sioux Falls, SD Suitland, MD Salt lake City, UT
Skylab – EREP/ Microwave Scatterometer Radiometer	13.9 GHz	11 km	$0\text{-}8^0$ incidence angle	Variable	1973,1974	Sioux Falls, S.D. Suitland, MD Salt lake City, UT
Skylab – EREP/ L-Band Radiometer	1.4 GHz	124 km		Variable	1973,1974	Sioux Falls, SD
Nimbus 1 – 7	Multispectral Radiometers (Visible/ Infrared)	4-55 km	Sub-Continent	Daily in selected period	Discontinuous coverage since 1964	Greenbelt, MD
Nimbus 5 - 7	0.81–4.45 GHz	20-150 km	Sub-Continent	Daily	Discontinuous coverage since 1972	Greenbelt, MD

Table 3 Groundwater targeting – Indian satellites

Satellite	Launch Date	Sensors	Altitude (km)	Applications
INSAT Series (Geostationary)				
INSAT – 1A	April, 1982	12, C Band Transponders 2 High Power S Band Transponders & VHRR	36,000	Meteorological Applications, Television and Radio Broadcasting
INSAT – 1B	August, 1983	12, C Band Transponders 2 High Power S Band Transponders & VHRR	36,000	Telecommunication Television Broadcast and Meteorological Applications
INSAT – 1C	July, 1988	12, C Band Transponders 2 High Power S Band Transponders & VHRR	36,000	Telecommunication Television Broadcast and Meteorological Applications
INSAT – 1D	June,1990	12, C Band Transponders 2 High Power S Band Transponders & VHRR	36,000	Telecommunication Television Broadcast and Meteorological Applications

Contd…

Table 3 (contd.)

Satellite	Launch Date	Sensors	Altitude (km)	Applications
INSAT – 2A	July, 1992	12, C Band & 6 extended C band transponders, 2 high power television broadcast transponders and VHRR	36,000	Telecommunication Television Broadcast and Meteorological Applications
INSAT – 2B	1993	12, C Band Transponders 2 High Power S Band Transponders & VHRR	36,000	Telecommunication Television Broadcast and Meteorological Applications
INSAT – 2C	1994	12, C Band & 6 extended C band transponders, 2 high power television broadcast transponders and VHRR	36,000	Telecommunication Television Broadcast and Meteorological Applications, Networking, M.O. Service
INSAT – 2D	1997	12, C Band & 6 extended C band transponders, 2 high power television broadcast transponders and VHRR	36,000	Telecommunication Television Broadcast and Meteorological Applications, Networking, M.O. Service
IRS Series (Sunsynchronous)				
IRS – 1A	March 17, 1988	LISS I & II	904	Natural Resources Management, Drought Monitoring, Flood Mapping, Oil & Mineral Exploration, Landuse & Wasteland Mapping etc.
IRS – 1B	August 29, 1991	LISS I & II	904	Natural Resources Management, Drought Monitoring, Flood Mapping, Oil & Mineral Exploration, Landuse & Wasteland Mapping etc.
IRS – 1C	Dec 29, 1991	PAN, LISS I, II & III, WIFS	904	Natural Resources Management, Drought Monitoring, Flood Mapping, Oil & Mineral Exploration, Landuse & Wasteland Mapping etc.
IRS – P3	March 21, 1996	MOS, WIFS	904	Natural Resources Management, Drought Monitoring, Flood Mapping, Oil & Mineral Exploration, Landuse & Wasteland Mapping etc.
IRS – 1D	MID, 1997 (Expected)	MOS, WIFS	904	Natural Resources Management, Drought Monitoring, Flood Mapping, Oil & Mineral Exploration, Landuse & Wasteland Mapping etc.

There are four major regions of Electro Magnetic Radiation (EMR) which are sensitive to the elements which are indicators of moisture in the soil and are being used in the operational sensors and platforms, these lie in the visible (0.3-0.7 μm), near infrared (0.72-3.0 μm), in the emitted terrestrial Infrared region (3.4-4.3 μm and 8.0-12.0 μm) and atmospheric windows in the microwave region between 1-30 cm wavelength.

REMOTE SENSING APPLICATIONS

In conventional methods the measurements are made at few points, the remote sensing technology has provided capability of repetitive monitoring of large areas with high observational density, the watershed characteristics and temporal variability of dynamic data e.g. rainfall, runoff, recharge, etc. and interpreted from remote sensing.

The geological and geomorphological factors which control the occurrence and distribution of groundwater are basically dependent on porosity and permeability of rocks and their recharge potential which are controlled by lithology, structures (such as joints, faults and fractures) and landforms which characteristically have porous and permeable strata. Thus remote sensing for groundwater is restricted to search of lithologies, micro-lineaments, morphology of geomorphic elements, land-use, land-cover and vegetation which help to locate suitable aquifers and subsurface moisture for locating targets for drilling and exploratory openings.

GEOMORPHOLOGICAL FACTORS

The occurrence of groundwater is associated with certain characteristic geomorphic elements, drainage and relief characteristics. The land-forms likely to contain relatively porous and permeable strata comprise flood plain deposits, paleo-channels, glacial outwash, moraines, deltas, alluvial fans, beach ridges, lakes, streams and moist depression etc., these serve as guides in groundwater targeting. The drainage characteristics of an area are also used as a guide for groundwater targeting. Areas with low drainage density indicate possible presence of aquifer material. The relief setting of a micro-watershed is an indicator of runoff and recharge potential of an area. The possibility of aquifer recharge in areas of accidental relief is poor; low lying areas have better chance of recharge. Groundwater targeting is carried out through appraisal of regional and local relief siting in micro-watershed, using stereomodels.

GEOLOGICAL FACTORS

The saturated geological formations which can yield water in significant quantities are defined as aquifers. Thus for occurrence of Groundwater the porosity and permeability of rock are characteristic features to qualify a lithology as aquifer as against a confining bed which may be aquiclude, aquifuge or aquitard. The porosity may be primary or secondary due to strain, which may be manifested as joints, faults, lineaments, etc. Table 4 presents the classification of aquifers based on type of porosity and lithology.

Table 4 Aquifers-based on lithology and type of porosity (after Anon, 1975)

Type of porosity	Sedimentary			Igneous and metamorphic	Volcanic	
	Consolidated	Unconsolidated	Carbonates		Consolidated	Unconsolidated
Inter-granular	–	Gravelly sand, Clayey sand, Sandy clay	–	Weathered zone of granite-gneiss	Weathered zone of basalt	Volcanic ejecta, and blocks and fragments, Ash
Inter-granular and fracture	Breccia Conglomerate Sandstone Slate	–	Zoogenic limestone Oolitic limestone Calcareous grit	–	Volcanic tuff Cinder Volcanic breccia Pumice Basalt Andesite Rhyolite	–
Fracture	–	–	Limestone Dolomite Dolomitic limestone	Granite Gneiss Gabbro Quartzite Diorite Schist Mica schist	–	–

Source: Todd (1980)

TOOLS FOR TARGETING GROUNDWATER OCCURRENCE

The factors which control the groundwater occurrence can be grouped as geological, geomorphological and meteorological parameters. These parameters are observed through remote sensing interpretation and are used as tools to draw logical deductions for assessment of the water holding capacity of the aquifer zone in an area. The spatial distribution and occurrence of potential aquifers are used as guides for groundwater targeting. The potential aquifers are recognized by convergence of evidence deduced from photographic and geotechnical elements (Table 5).

Table 5 Recognition elements

A. Photographic Elements	B. Geotechnical Elements
1. Tone	1. Landform
2. Texture	2. Land-use
3. Shape	3. Drainage
4. Size	4. Erosion
5. Pattern	5. Vegetation
	6. Structure
Convergence	
1. Association of elements	
2. Relationship	
3. Ground Truth - Real Time	
- Secondary Source	
4. Deduction/Conclusion	

GEOHYDROLOGICAL MILIEU FOR WELL SITING

Quaternary Alluvial Deposits

Well siting in Quaternary Alluvial Deposits is based on terrain conditions. The Quaternary Deposits can be treated under two groups namely, the Indo-Gangetic Alluvial Plain and Quaternary sediments which occur as narrow flood plain deposits of recent river system e.g. Ken, Banas, Chambal, Rehind, etc. in the crystalline basement. The remote sensing for well siting in the two types of quaternary alluvial deposits differ slightly.

Indo-Gangetic Alluvial Plain

In the Indo-Gengetic Plain the quantity of water is not a problem, the area is literally floating on the fresh water. The well siting in Indo-Gangatic plain is necessitated by the demand of groundwater quality. In certain tracks the aquifer occur as multi-layered system in which some zones are saline. The Remote Sensing is directed to identify potential saline zones which are to be avoided in well siting. The remotely sensed data are processed to enhance the salt affected soils which empirically exhibit spatial correlation with high salinity zones in the aquifer systems.

Quaternary Alluvial Deposits in Crytalline Rocks

The flood plain deposits of the river systems draining the crystalline basement of the Indian shield are explored by remote sensing technique for well siting. The shield areas which have no porosity and permeability are poor repository of groundwater (aquitard). The flood plains in the crystalline rocks are identified through remotely sensed data. The scars of the palaeo-channels, cut-off meanders and point bars, channel bars are identified and are chosen for well siting to obtain dependable supplies of groundwater. Buried pediments are good loci for well siting, the distance from mountain front is considered as favourable parameter for wells.

Hard Rock Areas

Sedimentary Basins

The groundwater targeting in sedimentary basins is carried out to identify suitable rocks and structure. In sedimentary basins like Vindhyans, Kurnools, Gondwanas, etc. the groundwater occurs as zone of saturation and as perched water table. The elements which are identified for targeting are enumerated as follows:

Well Siting Guides (a) Porous and Permeable lithologies like Sandstone and Conglomerate
(b) Gently dipping to sub-horizontal formational units
(c) Structural and Geomorphic valleys
(d) Interesting micro-lineaments
(e) Tectonic lineaments cutting across the formational boundaries.

The photographic and geotechincal elements which characterize the above lithologies and structural controls are used us guides in well siting in sedimentary basins.

Crystalline Rocks

The shield area of the world which are characterized by the presence of crystalline basement rocks like gneisses, granites and highly metamorphosed metasediments form aquitards and are generally not preferred for well siting. However, the need to provide drinking water for the cultural settlements has necessitated locating water resources in such areas. The water localization is controlled by fracture, patterns, joints, faults, etc. The remote sensing techniques are used to identify the micro and macro-lineaments, their intersection points provide loci for groundwater targeting .

Well Siting Guides The remotely sensed data are useful for identifying the micro-and macro-lineaments which are expressed by linear tone, linear texture, linear pattern of vegetation, linear distribution of soil moisture and presence of phreatophytes. The presence of the Xerophytic plants and dwarf vegetation characterized by tissue atrophy are used as negative filters for eliminating areas for groundwater exploration. The drainage pattern and density are also used as tools in groundwater targeting. The areas with low surface drainage density are preferred as high recharge areas as against areas with high drainage density where the surface runoff is inferred as high and thereby the possibility of moisture zones us rated as low, in the aquitard terrains. The success rate of groundwater in such areas is considered adequate if the bore well can provide one litre/min discharge through a hand pump.

Digital Lineament Enhancement

Besides visual interpretation techniques carried out for the identification of joints, fractures and faults, digital image processing has also been used, which provides more accurate results. The techniques used for lineament extraction include Fast Fourier Transform (FFT) analysis, directional filters, band ratioing etc.

Identification of the shear fractures, tensional fractures, healed fractures, etc. is attempted for groundwater targeting. The porosity and permeability on the linears will be maximum in tensile fractures and least among the healed fractures. To further enhance the accuracy and to minimize drilling failures, an integrated approach is most suitable by taking geophysical surveys, particularly resistivity surveys with remote sensing data output (Sinha et al., 1990).

GIS Approach for Groundwater Targeting

The well siting can be carried out by using multiple database approach for identification of geohydrological units and around Banda district, U.P., the remotely sensed data were spatially integrated with the various spatial data and non-spatial data on the groundwater characteristics. In the study area two major types of aquifers were identified namely, granitic and alluvial aquifers. The hydrologic units and granulometric parameters of the aquifers were spatially studied. The landform characteristics, geomorphology in the form of geomorphological map were interpreted from remotely sensed data (aerial photographs, image and selective field checks) around Banda. Hydrogeological map around Banda was prepared from groundwater discharge data and well canvassing. The raster and vector data integration generated the hydrogeological map. Spatial integration of geomorphological and hydrogeological data generated illuminated model as groundwater potentiality map of the area. This multiple data base integration provided a basis for planning and targeting water supply schemes in the Bharolahar block of Banda district, U.P.

Lineament Analyses and GIS

In a recent study Sander et al. (1996) developed a GIS approach for groundwater targeting using spatial correlation between lineament and targeted site. The remotely sensed data (imageries and photographs) are used for lineament extraction. Sander et al. (1996) classified the photo lineaments into three classes on the basis of their prominence. The study has not revealed the basis on which the most prominent and least prominent photo-lineaments were decided. They have given empirical relationship based on weightage factors for each lineament class to suggest bore hole score. The ratings for the various lineaments in a GIS based distance from the lineament are given on a continuous scale as per Table 6.

Table 6 The ratings of various lineaments in GIS-based distance

Distance of the well-site for the lineament	Rating
0 m (On the lineament)	5
60 m from the lineament	4
120 m from the lineament	3
180 m from the lineament	2
240 m from the lineament	1
> 300 m from the lineament	0

The rating of the site for borehole is determined by the following equation:

$$BH_{score} = 2.5L_r + 2.0P1_r + 1.75P2_r + 1.0P3_r \qquad (1)$$

where BH_{score} is borehole score; L_r is distance to LANDSAT TM lineaments; $P1_r$ is distance to most prominent air-photo-lineaments; $P2_r$ is distance to less prominent air photo-lineaments; and $P3_r$ is distance to least prominent air photo-lineaments.

The borehole score which may be obtained from the above equation is empirical and a threshold value is decided on the basis of the local statistics. The study carried out by Sander et al. (1996) was used for Tease area and was not applied to Nkawkaw area due to weak data control. The lineament intersection density has been found to be more reliable parameter for groundwater targeting as transmissive zones are more likely to occur among the intersecting lineaments (Iqbaluddin and Ali, 1986; Sinha et al., 1990).

Arid Zones

The arid zone in India is identified by the paucity of rainfall which ranges from 10 cm to 45 cm. Thus in the arid zone most efforts on groundwater targeting are directed to locate fossil water. In arid lands the necessity for groundwater mining arise due to human settlements. The drinking water supply in the arid regions is conventionally through water harvesting. The prolong drought years force population migration in arid lands. To overcome this natural disaster, drinking water supply mission undertook a massive programme for groundwater targeting in arid lands. The remote sensing techniques have been successfully used in different areas of the world for groundwater targeting in arid lands. The search for fossil water is directed in the sedimentary basins, palaeo—karst and palaeo-channels which lie below the sand cover.

Sedimentary Basins

Identification of the porous and permeable strata from aerial photos and images is made. The boreholes are planned and projected to puncture the suitable lithologies at depths below the existing water-table in the area. The drilling carried out in the Lathi Formation of Rajasthan has successful in location groundwater suitable for drinking purposes.

Palaeo-Karst

The arid land in India and Africa are known to have humid past. During the humid phase the karst topography developed extensively in the carbonates sequence in western Rajasthan. The groundwater occurs in the palaeo- karst in arid lands. The identification of the signatures of carbonate sequences from the aerial photographs and images can help in locating suitable target areas. The classic example of karst based groundwater sources in Rajasthan is the well of Padamshri Chandidan of Barunda village (near Jodhpur).

Palaeo-Channels

In the arid lands the microwave data have been used with success to identify the subsurface geomorphology. The classic case of identification of palaeo-channels from microwave data in the Salamia desert can be used as an example for groundwater targeting in the arid lands of India. The palaeo-channels associated with the Luni floodplain in western Rajasthan can be used as sites for groundwater well siting which are easily picked up in the remotely sensed data.

REFERENCES

Anon, (1975) Department of Economic and Social Affairs, Groundwater storage and artificial recharge. Natural Resources, Water Ser No. 2, United Nations, New York.

Fetter, C.W. (1980) Applied Hydrogeology. Charles E. Merril Publishing Company, Columbus, Ohio, U.S.A.

Iqbaluddin and Ali, S.A. (1986) Photogeophysical approach to stress analysis in cratonic basin- An example from Vindhyan Basin, Rajasthan, India. Proceedings of the Seventh Asian Conference on Remote Sensing, Seoul, Korea. E-6-1 to E-6-13.

Sander, P., Mathew, M.C. and Timothy, B.M. (1996) Groundwater assessment using Remote Sensing and LGISL in a rural groundwater project in Ghana: Lessons learned, Hydrogeol. J., 4, 40-49.

Siagal, S.B. and Gillespie, A.R. (1980) Remote Sensing in Geology, Jhon Wiley & Sons, New York.

Sinha, B.K., Kumar, A., Shrivastava, D. and Srivastava, S. (1990) Integrated Approach for Demarcating the Fracture Zone for well Site Location: A Case Study Near Gumla and Lohardaga, Bihar, J. Ind. Soc. Rem. Sens., Photonirvachak, 18, 1 – 8.

Todd, D.K. (1980) Groundwater Hydrology, Second Edition, John Wiley & Sons, New York.